Types and State-of-art Detection Paradigms of Black Holes

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Abstract. Contemporarily, mankind has been exploring the universe for a long time, as early as 1609 when Galileo started to observe the closer planets with telescopes. The universe has an indispensable and extremely important object of study, which is the black hole, a celestial body whose curvature of space-time reaches the point where light cannot escape. The paper selects black holes as the investigation target discussing from the following aspects. Primarily, the basic description of black holes will be given. Then, we present several characteristics and several types of black holes and explain their importance in the universe Subsequently, detection paradigms for the black holes will be discussed and analyzed. The significance of our study is to reflect the efforts and efforts of human beings in exploring the universe, and to study the mysterious object of black holes. According to the analysis, it is believed that in the future, after several generations of efforts and exploration, and the upgrade of technology, human beings will have a deeper understanding of the universe and the secrets of black holes will no longer exist. These results shed light on guiding further exploration regarding to black holes.

Keywords: Black holes; detection paradigms of black holes; types of black holes.

1. Introduction

The history of humans studying black holes started with knowing gravity. In 1687, Issac Newton sat under a tree and an apple fell, which is the first time that a human got some idea of gravity. After about a century, in 1783, the first idea about black hole evidence existed there is a letter that John Michell from Cambridge sent to Henry Cavendish. In the letter, it points out that a star with enough mass and density could let any light from a star return to the distance before being infinite. But that theory was not taken seriously [1]. In the early 20 century, Albert Einstein first put forward the restricted theory of relativity and general relativity, which overturned people's knowledge of gravity. [2] And several months later, Karl Schwarzschild from German gave an exact solution to Einstein's Gravitational Field Equation.

At 20 century 60s, there were two big breakthroughs. The first one was in 1963 when Roy Kerr first found the exact solution of Einstein's Gravitational Field Equation with a spinning black hole. And the second one is some scientists used the detection method to first find the black hole that exists in 1964 [3]. On January 5. In 2020, the Laser Interferometer Gravitational-wave Observatory (LIGO) first detected the event GW200105, the merging of neutron stars and black holes. This lets humans know what is going on in those super-mass celestial bodies [4]. On May 12 in 2022, The second black hole picture shoot by EHT was show to public, it was taken the same time as the first picture, but it is show to public later than the first one since there is a lot of data need to deal with.

In this paper, we will say something about and expand more of the type of black hole it needs and will be explored. The part following in this paper is use the order as the following. The Sec. 2 will show the basic description of black holes, which give a big overview about what is black hole. Section 3 will illustrate the basic description of a black hole, including its basic structure and basic definition. The Sec. 4 discusses about the detection paradigms, which is about the detection way of black holes

and with some examples. The Sec. 5 shows some special kind of black holes, and there are some examples. The Sec. 6 is about the limitations and future outlooks of studying black holes. We explain why detecting the black hole is still hard for human beings, and mad some prospects. At the very end, a summary will be given in Sec. 7.

2. Basic Black Holes' Descriptions

The black hole was a kind of celestial body that General relativity prophesied, and it is pretended that it exists [5]. A black hole is a celestial body with a big mass (the mass should be big enough to let the light not escape). Since the light cannot escape or reflect, and no light is sent out from the black hole, it makes the prediction harder, but there is evidence a black hole exists such as a star revolving in an empty space. Black holes are very special stars in space. They do not have any cosmological or physics meaningful features except for their mass, rotation, and charge [6]. It is also called the No-hair theorem of the black hole [7]. If two black holes are the same in mass, rotation, and charge, they cannot separate in physics. There are several types of black holes with different physical features which will be discussed in the following sections.

3. Types of Black Holes

Black holes can be categorized using a variety of standards.A typical sketch of various kinds of black holes are presented in Fig. 1. First, black holes are divided into four categories based on their mass. The first type is stellar black holes, which form when a star that is eight times as massive as the Sun died and collapsed. This type of black hole is common in the solar system. The second type is supermassive black holes. They weigh up millions or billions of times the mass of the Sun but have the relatively same size. By continuously feeding on some small planets or stars, these types of black holes grow all the time. Third, there's an intermediate black hole with a mass between the stellar black holes and supermassive black holes, approximately hundreds or thousands or ten of thousands of the Sun's mass. The last one is miniature or primordial black holes, which formed soon after the big bang. These black holes have a mass even less than the mass of the Sun, but their sizes are so small that they are super dense [8, 9].

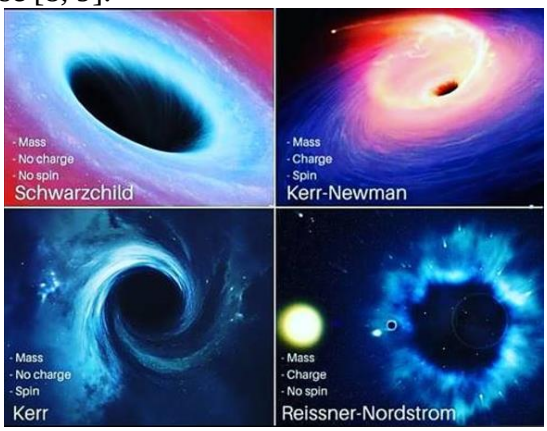


Fig. 1 A sketch of different types of black holes.

In addition, black holes can be classified by whether they spin and are charged [10]. Schwarzschild's solution to Einstein's equations for the gravitational field assumes that the source of gravity is spherically symmetric, has a mass M, is stationary, does not rotate, and has no charge. This type of black hole is called Schwarzschild black hole. Besides, Kerr found an axisymmetric solution to Einstein's equation of gravitational field, the source of which is asymmetrically distributed and its mass is M. It has no charge but is spinning, it has angular momentum, and its event horizon is

$$H = \frac{\mathrm{GM}+\sqrt{G^2M^2-a^2}}{c^2} \tag{1}$$

Where a is the angular momentum. The black holes corresponding to this solution are called Kerr black holes. Reissner and Nordstrom calculated another solution by assuming that the source of gravity is also stationary with a spherically symmetric distribution. This type of black hole has a mass of M, but a charge of Q and its gravitational radius is

$$H = \frac{\mathrm{GM}+\sqrt{G^2M^2-GQ^2}}{\mathrm{c}^2} \tag{2}$$

Finally, A normal black hole must have an axially symmetric source of gravity, this black hole has mass M, charge Q, and angular momentum a. This generic black hole is called a Kerr-Newman black hole, and its gravitational radius is defined as:

$$H = \frac{\mathrm{GM}+\sqrt{G^2M^2-GQ^2-a^2}}{c^2} \tag{3}$$

4. Detection Paradigims

Nowadays, there is no way for humans to directly discover black hole, but there are four ways to indirectly detect black holes. We can use gamma ray bursts to predict the black holes that will form. According to the NASA, if the mass of the sun is more than eight times that of the sun, and the mass of the core is more than three times that of the sun's core, such stars will collapse to form black holes and release gamma ray bursts at the end of their lives. So through gamma ray bursts (a sketch is presented in Fig. 2), telescopes can detect the initial black holes [10].



Fig. 2 A sketch of gamma burst.

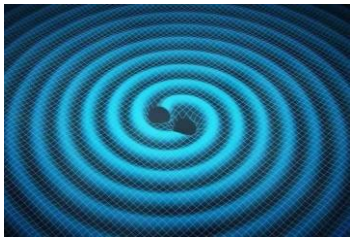


Fig. 3 A sketch of gravitational wave generation via blac hole merging.

Moreover, Detection gravitational waves can find black holes. When two black holes attract and rotate each other, they generate ripples in space-time due to gravitational interaction and propagate in the form of gravitational waves. Gravitational waves can be observed by laser interference gravitational wave observatory or radio telescope. A sketch of the gravitational wave generation by black holese merging is presented in Fig. 3. Gravitation waves are not only generated between two black holes, but also the interaction between black holes and neutron stars [11]. LIGO is a large instrument that uses laser interferometers to detect gravitational wave signals in the universe [12]. According to Einstein's gravitational field equation, we discovered the secret of gravity. In December 2018, LIGO discovered the largest black hole merger event to date. In August 2019, a gravitational wave pulse emitted between a black hole and a neutron star 900 million light-years away was discovered.

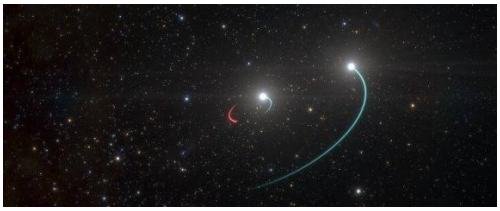


Fig. 4 Trajectories of black holes.

Gamma-ray bursts and gravitational waves are only brief high-energy events from black holes, which detectors can only occasionally detect. During the lifetime of most black holes, they emit no radiation. Due to its characteristics, it could not be discovered directly with any detector. However, due to the strong gravity of black holes, some black holes will have companions. The location of the black hole can also be inferred by observing the trajectory of the partner (seen from Fig. 4) [13]. Direct images of the telescope can reveal the presence of black holes. EHT (Event Horizon Telescope) is an observation network of 12 radio telescopes and arrays with participating members ARO, APEX, ASTE, CARMA, CSO, IRAM, JCMT, LMT, SMA, ALMA, NOEMA and SPT. The main observation mission objective of this project is Sagittarius A*, M87 and AGN. The project will observe the black holes of these galaxies, continuously detect the movement of black holes, and study black holes deeper [14].

The worst test was A0620-00. These are the two constellations of the Unicorn constellation. This galaxy has two major celestial bodies, a sequence star, and an unknown substance, which is regarded by scientists as a stellar-mass black hole. This system is 3000 (3000) light years away. The A0620-00 black hole binary galaxy A0620-00 synchrotron is shown for X-ray, ultraviolet, optical. in March 2010, near-infrared and radio observations were made of this system. Using the Cosmic Origin Spectrometer in the Hubble Space Telescope, we obtained the A0620-00 FUV spectrometer for the first time and made NUV observations on it. The observed spectrum is flat and weak in FUV (continuous flux -17ergcm-2s-1). In addition, UV also exhibits strong and wide (FWHM~2000 kms-1) radiation intensity and width (FWHM~2000 kms-1). Compared with other lines, the doublet of CIV is very weak, which is consistent with the low carbon abundance in the NIR spectrum [15].

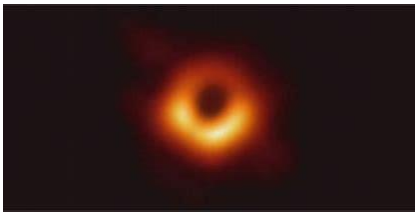


Fig. 5 Images of black holes.

Cygnus X-1 is in a active region of the Milky Way, it is a kind of stellar black hole that comes from a collape of a massive star, this black hole pulls matters frome a massive, blue companion star to form itself and those matters will form a disk as you can see in the Fig.6, it orbits the black holes before it collapse or redirected from the black hole. The sketch of it is presented in Fig. 6.

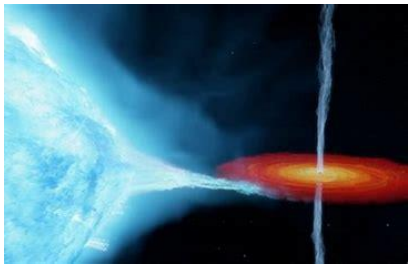


Fig. 6 Images of Cygnus X-1.

V404 Cygni is a massive ring: the black hole is located in a star system called V404 Cygni, about 7800 light-years from our Earth. The black hole is actively pulling matter from a moon with about half the mass of the sun, turning it into a disk around the invisible object. The last time one were detected was in 1989, due to its infrared burst.[16]. A sketch is depicted in Fig. 7.

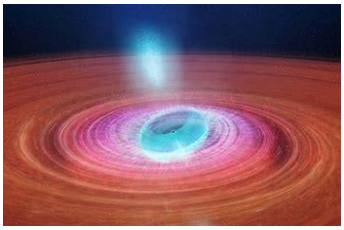


Fig. 7 Images of V404 Cygni.

5. Special Black Holes

There are many meaningful and special black holes in the universe, some of which have contributed greatly to the development of human science and the exploration of the universe, such as images of black holes that have allowed scientists to confirm the structure of black holes. First of all, supermassive black holes, the "monsters" of the universe, almost every galaxy, including our Milky Way, has a supermassive black hole in the center, the mass of these monster objects is extremely large, and can even reach thousands and tens of thousands of times the Sun, as for our Milky Way, there is a Sagittarius A* in the center, is the Sun 4 million times the mass - small compared to the black holes of other galaxies. As for planetary black holes, or planetary mass black holes, if a planet with a mass greater than 8 times the mass of the Sun runs out of fuel, its nucleus and surface collapse, rebound, and then become a supernova, which then explodes, leaving behind a product that depends on the mass before the explosion, and if the mass before the explosion is greater than 20 times that of the Sun, then a black hole is formed, i.e., the "dead zone" of the universe.

6. Limitations & Prospects

Gravitational waves from supermassive black holes are thought to prevent star formation in massive galaxies, including our own Milky Way galaxy. The largest galaxies in the universe are located at the center of galaxy clusters (e.g., there is a massive black hole at the center of our Milky Way), which is more detailed feedback of information. We will review the limitations and details of black hole feedback in massive galaxies, and summarize the cooling/feedback balance of 10 Gyr galaxies through an in-depth study of these largest masses. The most distant black hole discovered so far is about 13.1 billion light years away. (It already exists because the universe is 13.8 billion years old). Such super black holes are called "quasars" by astronomers. Large amounts of gas enter the black hole at extremely fast speeds, releasing more than 1000 times the energy of the galaxy itself. Its extreme brightness allows astronomers to spot it from such a great distance.

Scholars continue to develop computer simulations to help future observations get a better handle on data about black holes, the most elusive objects in the universe. Although black holes may exist in abundance in the universe, they are notoriously difficult to see. Scientists did not capture images of black holes for the first time until 2019, and only about 40 or so black hole mergers have been detected through their signature gravitational waves since they were first found in 2015. This is not a huge amount of data to work with. Scientists are therefore looking to black hole simulations to gain critical observational power that will help find more mergers through future missions. Some of these simulations, created by scientists These simulations were created by computers through systems of equations too complex to solve by hand; illustrating how matter interacts in a merging environment. Nowadays, scientists can only study by using computer simulations, even if the amount of data is not large, and the image of a black hole was not captured until 2019, which shows the limitations of the study of black holes

The TianQin space gravitational wave detector program, currently led by China, is expected to be launched between 2030-2035, deploying three satellites orbiting the Earth at an altitude of 100,000 km, forming an equilateral triangle with an arm length of 170,000 km to form a space gravitational wave detector. The Lyrae gravitational wave detector will be able to detect the gravitational waves

generated by the merger of two large black holes formed by the collapse of the first generation of stars or gas clouds at the beginning of the universe, which will help us understand major astronomical and physical questions such as the early seed black holes of the universe, the growth history of black holes, and the evolution of galaxies. Therefore, the Lyra space gravitational wave program will certainly be a powerful tool to detect cosmic black holes in the next 20 years, especially the possibility of searching for a large number of intermediate mass black holes.

The detection of unknown objects is always expected, and the era of gravitational wave astronomy has begun. In the future, there will be more equipment for black hole observation and the technology will be improved a lot. Hence, based on humanity's achievements in recent years we may still use the space telescope with faster signal with the satellites to create a web for example the Space X star chain to explore the universe more widely, and cover more space so that we can find more new black holes. Besides, one can built more gravitational waves detector that use gravity to find black holes because Gravitational waves can span large distances and dimensions and still be detected. In addition, black holes may give us more chance to create new technologies like: time travel or even creating a wormhole to enter another galaxy in few hours. The hymn of humanity is the hymn of courage human beings will never stop exploring.

7. Conclusion

In summary, this study discusses the basic concept, types, and the detection paradigms of the black holes. To be specifical, the black hole is a special celestial body that is pretended to exist and is suggested in General relativity. In general, the black hole has so big a mass that no light can escape from it. Moreover, it has no cosmological features besides their mass rotation and charge. According to the analysis, the black hole can be divided into four categories by their mass-stellar black holes, supermassive black holes, intermediate black holes, and miniature black holes Besides, there is another way to classify them, which is explore whether they spin or are charged-Schwarzschilds' black holes, Kerr black holes, Kerr-Newman black holes, and Reisser-Nordstorm black holes Nevertheless, we are limited in the detection of the black holes for their invisibility. One can only detect the black hole by their Gamma-ray bursts and gravitational waves, which are only brief high energy events. In the future, more and more simulations about the black hole will be available and scientists can therefore illustrate some different between the black hole merger and the stellar events and then learn more about black holes Overall, these results offer a guideline for the future research and the detection of the black holes.

References

[1] Israel W. Dark stars: the evolution of an idea. Three hundred years of gravitation, 1987: 199-276.

[2] Shen Z. The first photograph of a black hole in human history has been published. Science Foundation of China, 2020, 34(02): 193-194.

[3] Lu Y, Guo X. A neutron star-black hole merger has been detected for the first time. Chinese Science Bulletin, 2022, 67(22): 6.

[4] Wu Y. The first image of the black hole at the center of our galaxy. Journal of Nature, 2022, 44(3): 2.

[5] Bento M C, Bertolami O, Mourão J M, et al. Classical and Quantum Gravity. Institute of Physics, 1992

[6] Sudarsky D. A simple proof of a no-hair theorem in Einstein-Higgs theory. Classical & Quantum Gravity, 1995, 12 (2): 579

[7] Jiao C. Global Solution of Black hole Slim Disk. Xiamen University, 2010.

[8] Charles N. What Are the Types of Black Holes? April 25, 2022, futurespaceworld. Available from https://www.futurespaceworld.com/what-are-the-types-of-black-holes

[9] Black holes. NASA Science. Available from https://universe.nasa.gov/black-holes/types/

[10] Huang X L, Yuan L, Zhou J Q. Fundamental Rules of Formation, Evolution and structure of Primary Typical Stars and Their Nuclei Black Holes. Journal of Shaoyang University: Natural Science Edition, 2008, 3: 28-37.

[11] Yuan Y F. Black hole binaries in the universe. Scientia Sinica Physica, Mechanica & Astronomica, 2017, 47(1): 15.

[12] Hu Y M. Detecting gravitational wave with LIGO: The beginning of a new era. Chinese Journal of Nature, 2016, 38(02): 79-86.

[13] Bodensteiner J, Shenar T, Mahy L, et al. Is HR 6819 a triple system containing a black hole?-An alternative explanation. Astronomy & Astrophysics, 2020, 641: A43.

[14] Li X Z. Event Horizon Telescope. Science, 2017, 69(03): 17-22.

[15] Mushotzky R F, Edelson R, Baumgartner W, et al. Kepler observations of rapid optical variability in active galactic nuclei. The Astrophysical Journal Letters, 2011, 743(1): L12.

[16] Hernández J I G, Casares J, Rebolo R, et al. Chemical abundances of the secondary star in the black hole X-ray binary V404 Cygni. The Astrophysical Journal, 2011, 738(1): 95.